CHAPTER 5

ENGINE STARTING SYSTEMS

GENERAL

Most aircraft engines are started by a device called a starter. A starter is a mechanism capable of developing large amounts of mechanical energy that can be applied to an engine, causing it to rotate.

In the early stages of aircraft development, relatively low-powered engines were started by pulling the propeller through a part of a revolution by hand. Some difficulty was often experienced in cold weather starting when lubricating oil temperatures were near the congealing point. In addition, the magneto systems delivered a weak starting spark at the very low cranking speeds. This was often compensated for by providing a hot spark, using such ignition system devices as the booster coil, induction vibrator, or impulse coupling.

Some small, low-powered aircraft which use hand-cranking of the propeller for starting are still being operated. For general instructions on starting this type of aircraft, refer to the Airframe and Powerplant Mechanics General Handbook, AC 65–9, Chapter 11.

RECIPROCATING ENGINE STARTING SYSTEMS

Throughout the development of the aircraft reciprocating engine from the earliest use of starting systems to the present, a number of different starter systems have been used. The most common of these are:

(1) Cartridge starter. (Not in common use.)

(2) Hand inertia starter. (Not in common use.)

(3) Electric inertia starter. (Not in common use.)

(4) Combination inertia starter. (Not in common use.)

(5) Direct-cranking electric starter.

Most reciprocating engine starters are of the direct-cranking electric type. A few older model aircraft are still equipped with one of the types of inertia starters, and in very rare instances an example of the hand cranking, hand inertia, or cartridge starter may be found. Thus, only a brief description of these starting systems is included in this section.

Inertia Starters

There are three general types of inertia starters: (1) Hand inertia starters, (2) electric inertia starters, and (3) combination hand and electric inertia starters.

The operation of all types of inertia starters depends on the kinetic energy stored in a rapidly rotating flywheel for cranking ability. (Kinetic energy is energy possessed by a body by virtue of its state of motion, which may be movement along a line or spinning action.) In the inertia starter, energy is stored slowly during an energizing process by a manual hand crank or electrically with a small motor. The flywheel and movable gears of a combination hand electric inertia starter are shown in figure 5–1. The electrical circuit for an electric inertia starter is shown in figure 5–2.

During the energizing of the starter, all movable parts within it, including the flywheel, are set in motion. After the starter has been fully energized, it is engaged to the crankshaft of the engine by a cable pulled manually or by a meshing solenoid which is energized electrically. When the starter is engaged or meshed, flywheel energy is transferred to the engine through sets of reduction gears and a torque overload release clutch (see figure 5–3).

Direct-Cranking Electric Starter

The most widely used starting system on all types of reciprocating engines utilizes the direct-cranking electric starter. This type of starter provides instant and continual cranking when ener-

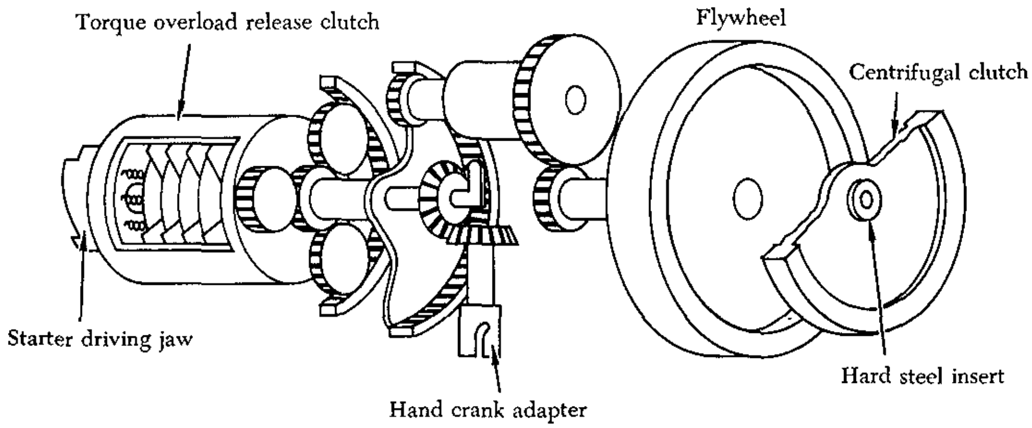

FIGURE 5–1. **Combination hand and electric inertia starter.**

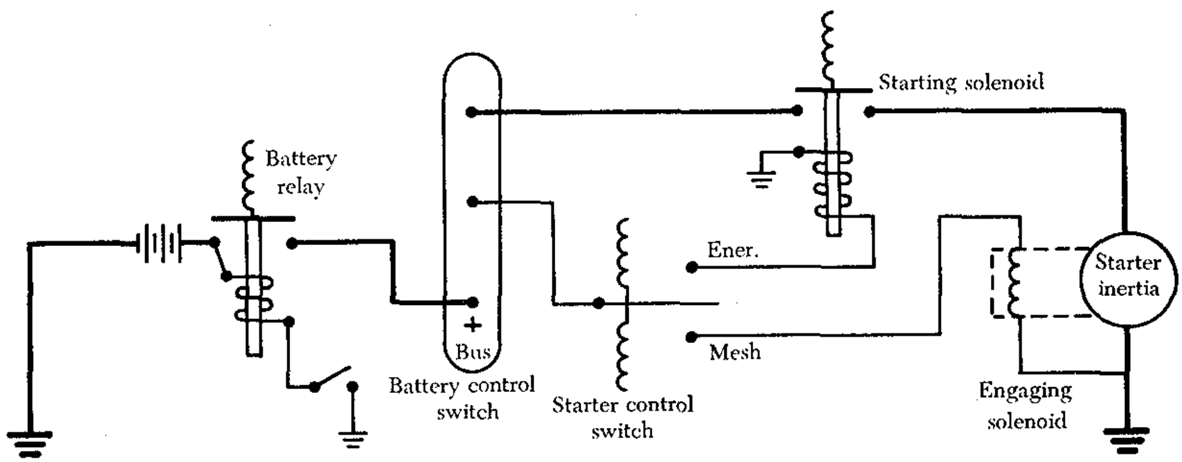

FIGURE 5–2. **Electric inertia starting circuit.**

gized. The direct-cranking electric starter consists basically of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism which is operated through an adjustable torque overload release clutch. A typical circuit for a direct-cranking electric starter is shown in figure 5–4.

The engine is cranked directly when the starter solenoid is closed. Since no flywheel is used in the direct-cranking electric starter, there is no preliminary storing of energy as in the case of an inertia starter.

As shown in figure 5–4, the main cables leading from the starter to the battery are heavy-duty to carry the high-current flow which may be as high as 350 amperes, depending on the starting torque

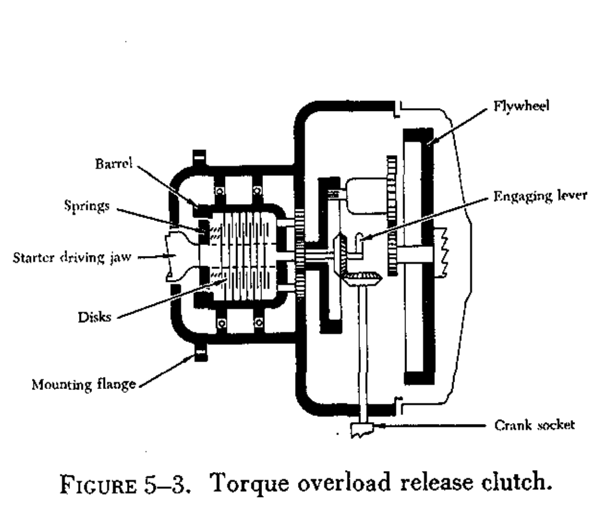

FIGURE 5–3. **Torque overload release clutch.**

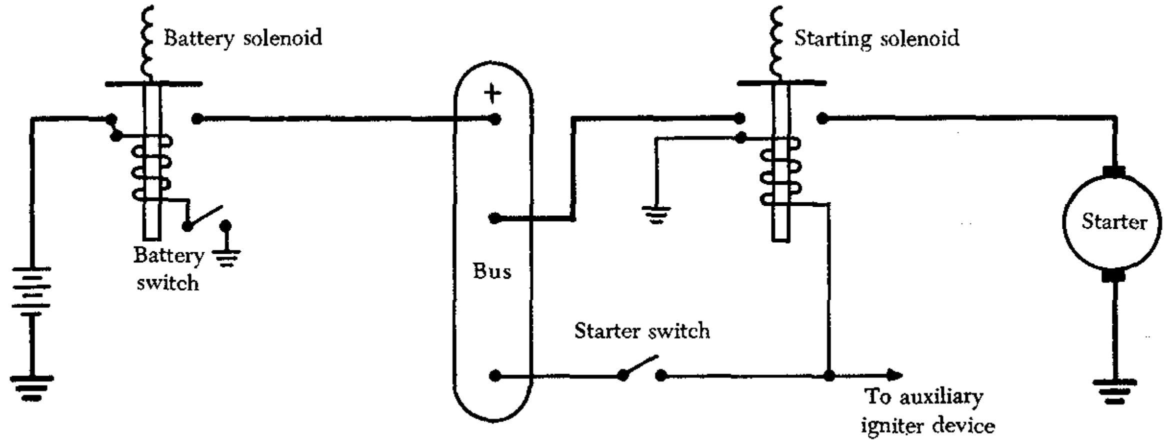

FIGURE 5–4. Typical starting circuit using a direct-cranking electric starter.

required. The use of solenoids and heavy wiring with a remote control switch reduces overall cable weight and total circuit voltage drop.

The typical starter motor is a 12- or 24-volt, series-wound motor, which develops high starting torque. The torque of the motor is transmitted through reduction gears to the overload release clutch. Typically, this action actuates a helically splined shaft, moving the starter jaw outward to engage the engine cranking jaw before the starter jaw begins to rotate. After the engine reaches a predetermined speed, the starter automatically disengages.

The schematic in figure 5–5 provides a pictorial arrangement of an entire starting system for a light twin-engine aircraft.

STARTING SYSTEM USING COMBINATION INERTIA STARTER

The following discussion covers one type of starting system used on a large reciprocating twin-engine aircraft. This system includes, for each engine, a combination inertia starter, a booster coil, a single-pole, double-throw switch in the cockpit, and the necessary solenoids and wiring. The combination inertia starter is shown in figure 5–6.

External hand-starting controls, incorporating a starter crank extension and a starting control cable, are provided for starting the engine by hand (figure 5–7).

Two starter switches are located on the cockpit electrical panel. Placing a switch in the "up" position operates the starter. The same switch, placed in the "down" position, operates the meshing (starter-engaging) solenoid and the ignition booster coil. The "off" position of the switch is midway between the two other positions.

A battery-operated booster coil, mounted in a shielded case, is installed on the engine mount of each engine. Flexible conduit shields the leads from the coil to one of the magnetos on each engine.

DIRECT-CRANKING ELECTRIC STARTING SYSTEM FOR LARGE RECIPROCATING ENGINES

In a typical high-horsepower reciprocating engine starting system, the direct-cranking electric starter consists of two basic components: a motor assembly and a gear section. The gear section is bolted to the drive end of the motor to form a complete unit.

The motor assembly consists of the armature and motor pinion assembly, the end bell assembly, and the motor housing assembly. The motor housing also acts as the magnetic yoke for the field structure.

The starter motor is a nonreversible, series interpole motor. Its speed varies directly with the applied voltage and inversely with the load.

The starter gear section, shown in figure 5–8, consists of a housing with an integral mounting flange, planetary gear reduction, a sun and integral gear assembly, a torque-limiting clutch, and a jaw and cone assembly.

When the starter circuit is closed, the torque developed in the starter motor is transmitted to the starter jaw through the reduction gear train and clutch. The starter gear train converts the high-speed low-torque of the motor to the low-speed high-torque required to crank the engine.

In the gear section the motor pinion engages the gear on the intermediate countershaft. (Refer to figure 5–8). The pinion of the countershaft engages the internal gear. The internal gear is an integral part of the sun gear assembly and is rigidly attached

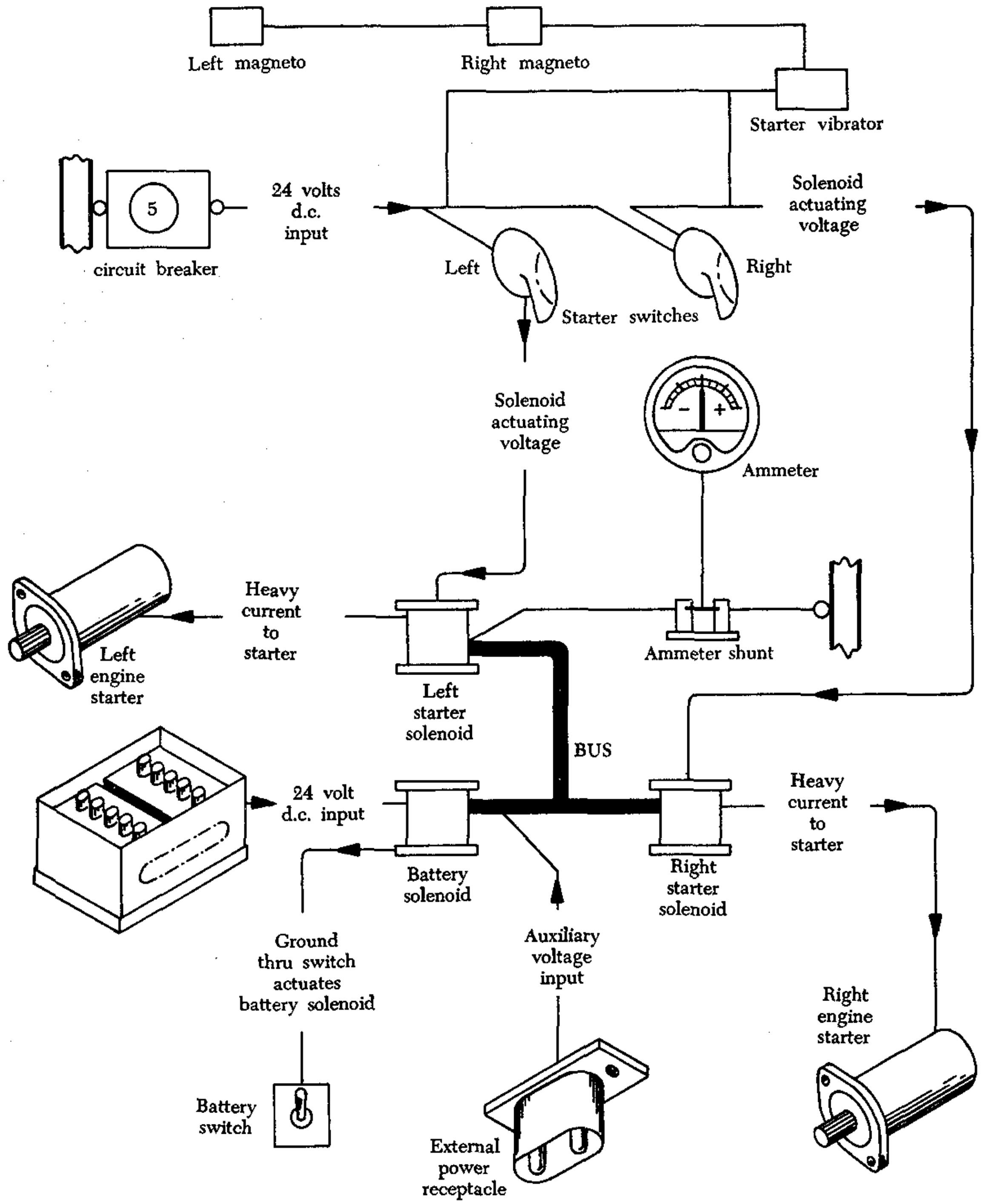

FIGURE 5–5. Engine starting schematic for a light twin-engine aircraft.

to the sun gear shaft. The sun gear drives three planet gears, which are part of the planetary gear assembly.

The individual planet gear shafts are supported by the planetary carrying arm, a barrel-like part shown in figure 5–8. The carrying arm transmits torque from the planet gears to the starter jaw as follows:

(1) The cylindrical portion of the carrying arm is splined longitudinally around the inner surface.

(2) Mating splines are cut on the exterior surface

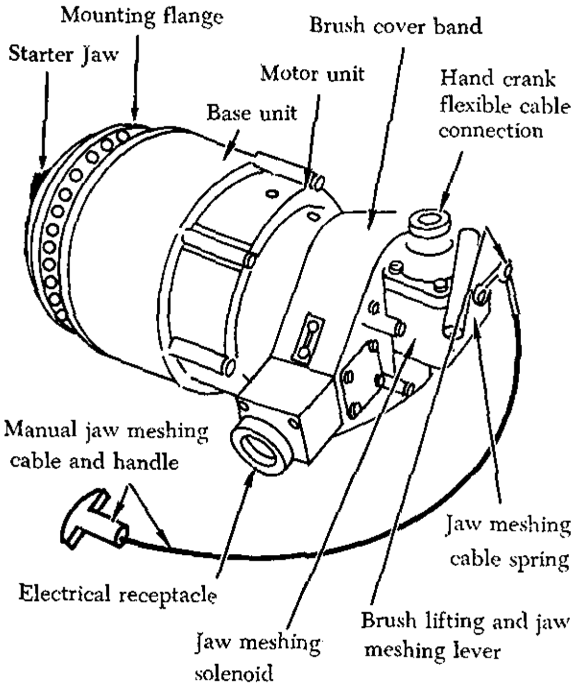

FIGURE 5–6. Combination inertia starter.

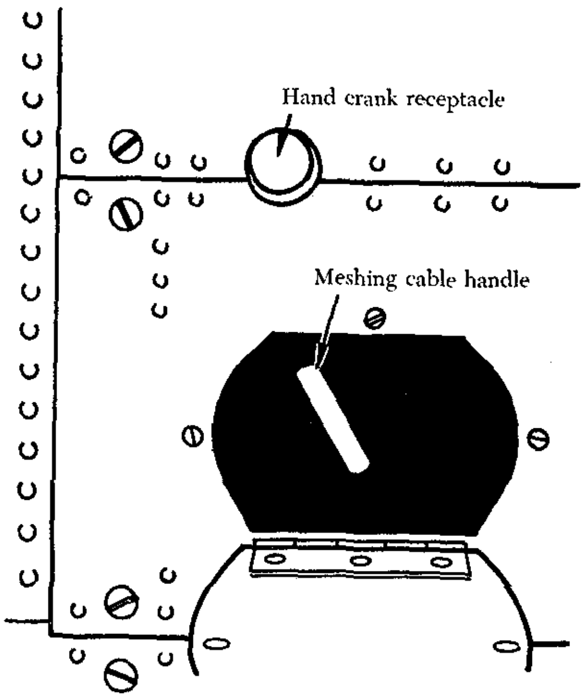

FIGURE 5–7. Hand-starting controls.

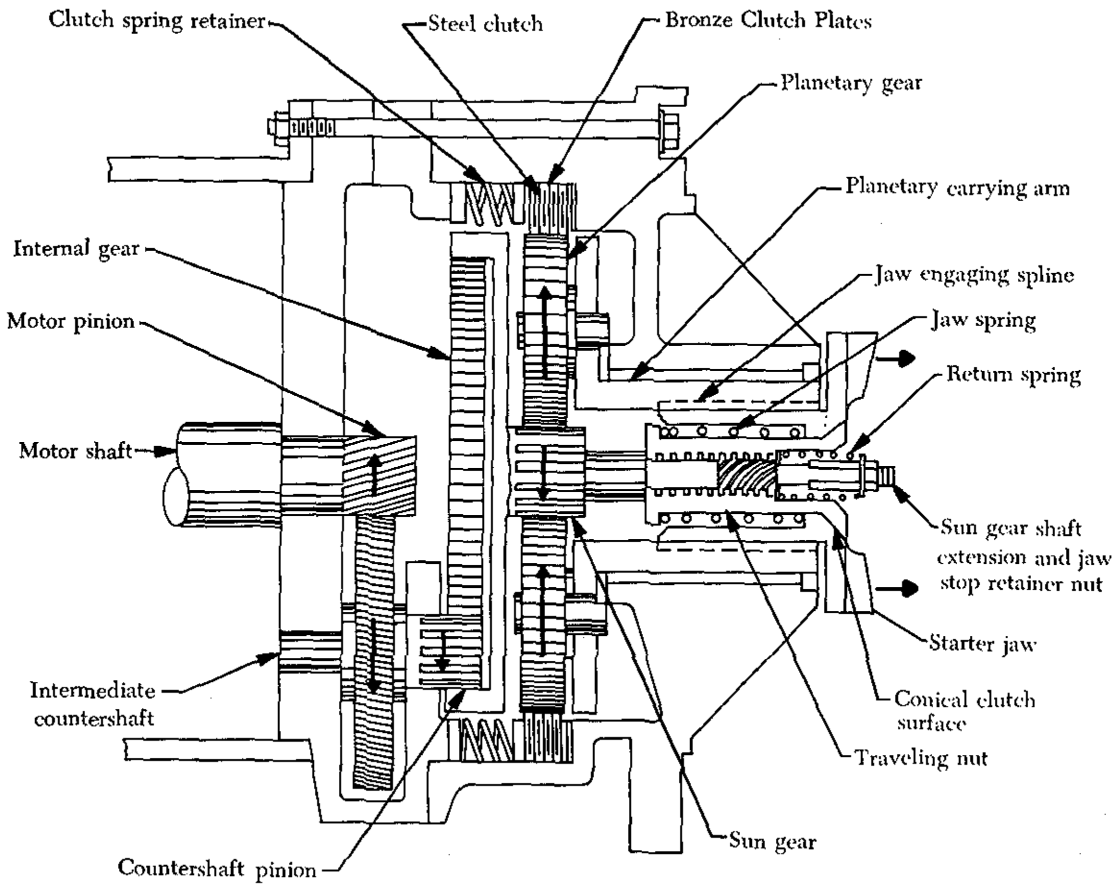

FIGURE 5–8. Starter gear section.

of the cylindrical part of the starter jaw.

(3) The jaw slides fore and aft inside the carrying arm to engage and disengage with the engine.

The three planet gears also engage the surrounding internal teeth on the six steel clutch plates (figure 5–8). These plates are interleaved with externally splined bronze clutch plates which engage the sides of the housing, preventing them from turning. The proper pressure is maintained upon the clutch pack by a clutch spring retainer assembly.

A cylindrical traveling nut inside the starter jaw extends and retracts the jaw. Spiral jaw-engaging splines around the inner wall of the nut mate with similar splines cut on an extension of the sun gear shaft (figure 5–8). Being splined in this fashion, rotation of the shaft forces the nut out and the nut carries the jaw with it. A jaw spring around the traveling nut carries the jaw with the nut and tends to keep a conical clutch surface around the inner wall of the jaw head seated against a similar surface around the under side of the nut head. A return spring is installed on the sun gear shaft extension between a shoulder formed by the splines around the inner wall of the traveling nut and a jaw stop retaining nut on the end of the shaft.

Because the conical clutch surfaces of the traveling nut and the starter jaw are engaged by jaw spring pressure, the two parts tend to rotate at the same speed. However, the sun gear shaft extension turns six times faster than the jaw. The spiral splines on it are cut left hand, and the sun gear shaft extension, turning to the right in relation to the jaw, forces the traveling nut and the jaw out from the starter its full travel (about 5/16 in.) in approximately 12° of rotation of the jaw. The jaw moves out until it is stopped either by engagement with the engine or by the jaw stop retaining nut. The travel nut continues to move slightly beyond the limit of jaw travel, just enough to relieve some of the spring pressure on the conical clutch surfaces.

As long as the starter continues to rotate, there is just enough pressure on the conical clutch surfaces to provide torque on the spiral splines which balances most of the pressure of the jaw spring. If the engine fails to start, the starter jaw will not retract, since the starter mechanism provides no retracting force. However, when the engine fires and the engine jaw overruns the starter jaw, the sloping ramps of the jaw teeth force the starter jaw into the starter against the jaw spring pressure. This disengages the conical clutch surfaces entirely, and the jaw spring pressure forces the traveling nut to slide in along the spiral splines until the conical clutch surfaces are again in contact.

With the starter and engine both running, there will be an engaging force keeping the jaws in contact, which will continue until the starter is deenergized. However, the rapidly moving engine jaw teeth, striking the slowly moving starter jaw teeth, hold the starter jaw disengaged. As soon as the starter comes to rest, the engaging force is removed, and the small return spring will throw the starter jaw into its fully retracted position, where it will remain until the next start.

When the starter jaw first engages the engine jaw, the motor armature has had time to reach considerable speed because of its high starting torque. The sudden engagement of the moving starter jaw with the stationary engine jaw would develop forces sufficiently high to severely damage the engine or the starter were it not for the plates in the clutch pack, which slip when the engine torque exceeds the clutch-slipping torque.

In normal direct-cranking action, the internal gear clutch plates (steel) are held stationary by the friction of the bronze plates, with which they are interleaved. When the torque imposed by the engine exceeds the clutch setting, however, the internal gear clutch plates rotate against the clutch friction, which allows the planet gears to rotate while the planetary carrying arm and the jaw remain stationary. When the engine comes up to the speed at which the starter is trying to drive it, the torque drops off to a value less than the clutch setting, the internal gear clutch plates are again held stationary, and the jaw rotates at the speed at which the motor is attempting to drive it.

The starter control switches are shown schematically in figure 5–9. The engine selector switch must be positioned, and both the starter switch and the safety switch (wired in series) must be closed before the starter can be energized.

Current is supplied to the starter control circuit through a circuit breaker, labeled "Starter, Primer, and Induction Vibrator" in figure 5–9. When the engine selector switch is in position for the engine start, closing the starter and safety switches energizes the starter relay located in the firewall junction box.

Energizing the starter relay completes the power circuit to the starter motor. The current necessary for this heavy load is taken directly from the master bus through the starter bus cable.

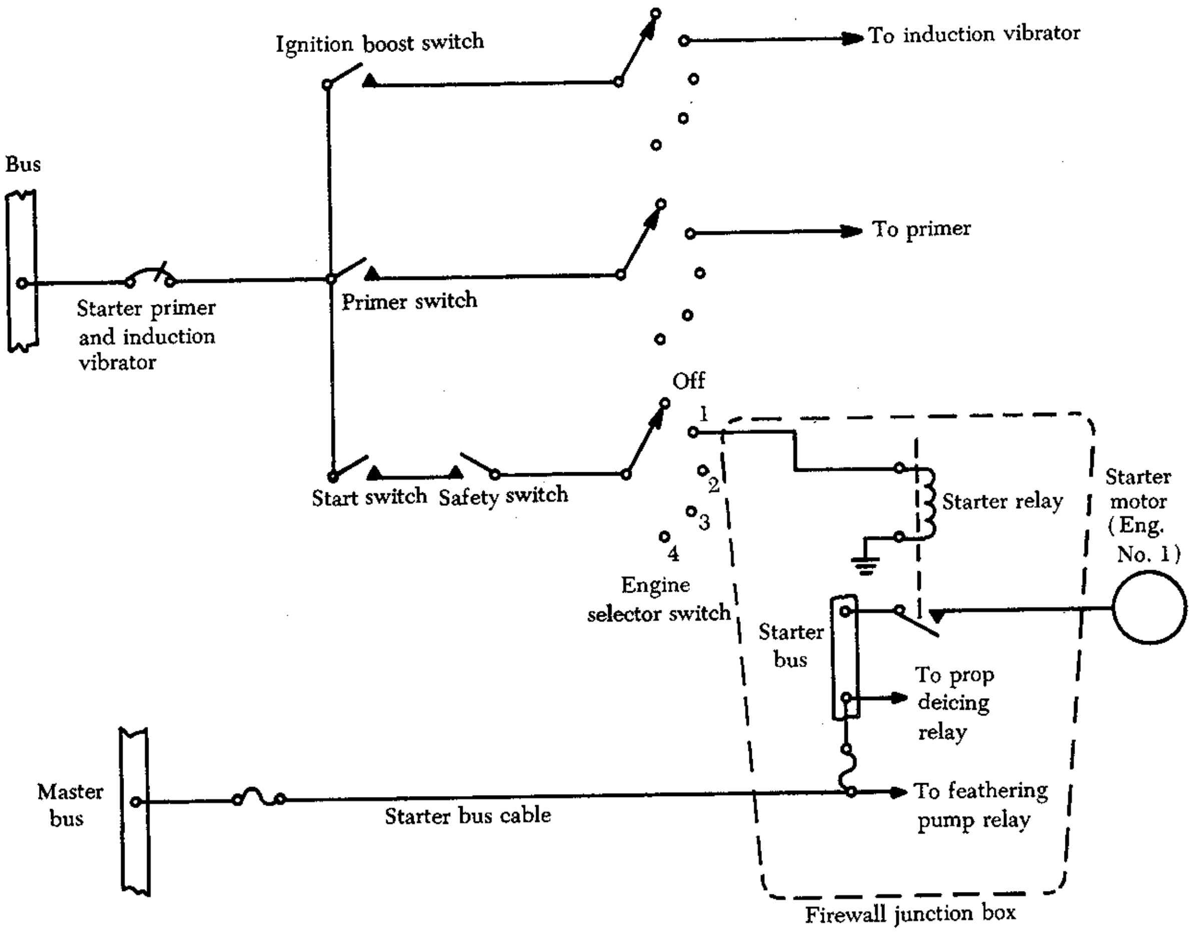

FIGURE 5–9. Starter control circuit.

After energizing the starter for 1 minute, it should be allowed to cool for at least 1 minute. After a second or subsequent cranking period of 1 minute, it should cool for 5 minutes.

DIRECT-CRANKING ELECTRIC STARTING SYSTEM FOR SMALL AIRCRAFT

Most small reciprocating-engine aircraft employ a direct-cranking electric starting system. Some of these systems are automatically engaged starting systems, while others are manually engaged.

The automatically engaged starting systems employ an electric starter mounted on an engine adapter. A starter solenoid is activated by either a push button or an ignition key on the instrument panel. When the solenoid is activated, its contacts close and electrical energy energizes the starter motor. Initial rotation of the starter motor engages the starter through an overrunning clutch in the starter adapter, which incorporates worm reduction gears.

Manually engaged starting systems on many small aircraft employ a manually operated overrunning-clutch drive pinion to transmit power from an electric starter motor to a crankshaft starter drive gear (see figure 5–10). A knob or handle on the instrument panel is connected by a flexible control to a lever on the starter. This lever shifts the starter drive pinion into the engaged position, and closes the starter switch contacts when the starter knob or handle is pulled. The starter lever is attached to a return spring which returns the lever and the flexible control to the "off" position. When the engine starts, the overrunning action of the clutch protects the starter drive pinion until the shift lever can be released to disengage the pinion.

As shown for the typical unit in figure 5–10, there is a specified length of travel for the starter gear pinion. It is important that the starter lever move the starter pinion gear this proper distance before the adjustable lever stud contacts the starter switch.

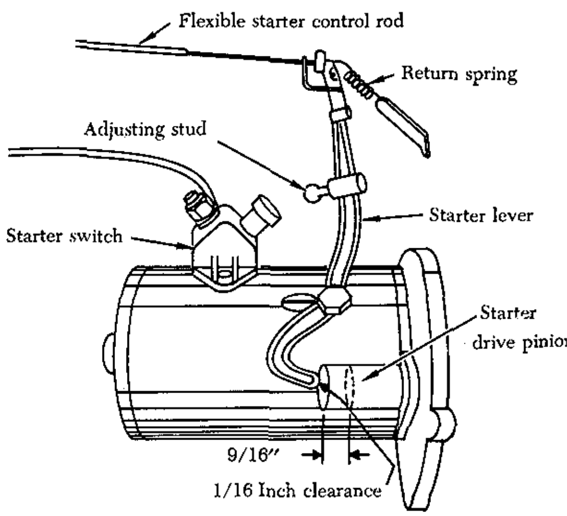

FIGURE 5–10. Starter lever controls and adjustment.

Starting System Maintenance Practices

Most starting system maintenance practices include replacing the starter brushes and brush springs, cleaning dirty commutators, and turning down burned or out-of-round starter commutators.

As a rule, starter brushes should be replaced when worn down to approximately one-half their original length. Brush spring tension should be sufficient to give brushes a good firm contact with the commutator. Brush leads should be unbroken and lead terminal screws tight.

A glazed or dirty starter commutator can be cleaned by holding a strip of double-0 sandpaper or a brush seating stone against the commutator as it is turned. The sandpaper or stone should be moved back and forth across the commutator to avoid wearing a groove. Emery paper or carborundum should never be used for this purpose because of their possible shorting action.

Roughness, out-of-roundness, or high-mica conditions are reasons for turning down the commutator. In the case of a high-mica condition, the mica should be undercut after the turning operation is accomplished. (Refer to the Airframe and Powerplant Mechanics General Handbook, AC 65–9 for a review of high-mica commutators in motors.)

Troubleshooting Small Aircraft Starting Systems

The troubleshooting procedures listed in table 6 are typical of those used to isolate malfunctions in small aircraft starting systems.

GAS TURBINE ENGINE STARTERS

Gas turbine engines are started by rotating the compressor. On dual-axial-compressor engines, the high-pressure compressor is the only one rotated by the starter. To start a gas turbine engine it is necessary to accelerate the compressor to provide sufficient air to support combustion in the burners. Once fuel has been introduced and the engine has fired, the starter must continue to assist the engine to reach a speed above the self-accelerating speed of the engine. The torque supplied by the starter must be in excess of the torque required to overcome compressor inertia and the friction loads of the engine.

The basic types of starters which have been developed for gas turbine engines are d.c. electric motor, air turbine, and combustion. An impingement starting system is sometimes used on small engines. An impingement starter consists of jets of compressed air piped to the inside of the compressor or turbine case so that the jet air-blast is directed onto the compressor or turbine rotor blades, causing them to rotate.

The graph in figure 5–11 illustrates a typical starting sequence for a gas turbine engine, regardless of the type of starter employed.

As soon as the starter has accelerated the compressor sufficiently to establish airflow through the engine, the ignition is turned on, and then the fuel. The exact sequence of the starting procedure is important since there must be sufficient airflow through the engine to support combustion before the fuel/air mixture is ignited. At low engine cranking speeds, the fuel flow rate is not sufficient

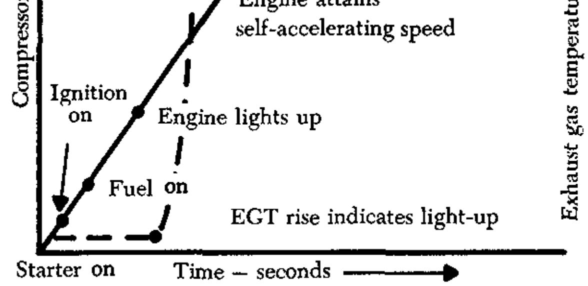

FIGURE 5–11. Typical gas turbine engine starting sequence.

TABLE 6. Small Aircraft Troubleshooting Procedures.

PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
Starter Will Not Operate:		
Defective master switch or circuit.	Check master circuit.	Repair circuit.
Defective starter switch or switch circuit.	Check switch circuit continuity.	Replace switch or wires.
Starter lever does not activate switch.	Check starter lever adjustment.	Adjust starter lever in accordance with manufacturer's instructions.
Defective starter.	Check through items above. If another cause is not apparent, starter is defective.	Remove and repair or replace starter.
Starter Motor Runs, But Does Not Turn Crankshaft:		
Starter lever adjusted to activate switch without engaging pinion with crankshaft gear.	Check starter lever adjustment.	Adjust starter lever in accordance with manufacturer's instructions.
Defective overrunning clutch or drive.	Remove starter and check starter drive and overrunning clutch.	Replace defective parts.
Damaged starter pinion gear or crankshaft gear.	Remove and check pinion gear and crankshaft gear.	Replace defective parts.
Starter Drags:		
Low battery.	Check battery.	Charge or replace battery.
Starter switch or relay contacts burned or dirty.	Check contacts.	Replace with serviceable unit.
Defective starter.	Check starter brushes, brush spring tension for solder thrown on brush cover.	Repair or replace starter.
Dirty, worn commutator.	Clean, and check visually.	Turn down commutator.
Starter Excessively Noisy:		
Worn starter pinion.	Remove and examine pinion.	Replace starter drive.
Worn or broken teeth on crankshaft gears.	Remove starter and turn over engine by hand to examine crankshaft gear.	Replace crankshaft gear.

to enable the engine to accelerate, and for this reason the starter continues to crank the engine until after self-accelerating speed has been attained. If assistance from the starter were cut off below the self-accelerating speed, the engine would either fail to accelerate to idle speed, or might even decelerate because it could not produce sufficient energy to sustain rotation or to accelerate during the initial phase of the starting cycle. The starter must continue to assist the engine considerably above the self-accelerating speed to avoid a delay in the starting cycle, which would result in a hot or hung (false) start, or a combination of both. At the proper points in the sequence, the starter and usually the ignition will be automatically cut off.

Electric Starting Systems

Electric starting systems for gas turbine aircraft are of two general types: (1) Direct-cranking electrical systems and (2) starter-generator systems.

Direct-cranking electric starting systems are similar to those used on reciprocating engines. Starter-generator starting systems are also similar to direct-cranking electrical systems. Electrically, the two systems may be identical, but the starter-generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct-cranking starter must employ some means of disengaging the starter from the shaft after the engine has started.

Direct-Cranking Gas Turbine Starters

On some direct-cranking starters used on gas turbine engines no overload release clutch or gear reduction mechanism is used. This is because of the low torque and high speed requirement for starting gas turbine engines. A reduced voltage mechanism is utilized, however, in the starting systems to prevent damage to the engaging assembly during starting.

Figure 5–12 shows the circuit of a reduced voltage control. The mechanism is mounted in an explosion-proof housing which contains five relays and a 0.042-ohm resistor. When the battery switch is closed, the time-delay relay coil is energized. The ground circuit for the coil of this relay is completed through the starter.

When the starter switch is moved to the start position, a circuit is completed to the coil of the acceleration relay. The closed relay contacts complete a circuit from the bus through the closed contacts, the 0.042-ohm resistor, the series relay coil, and finally through the starter motor to ground. Since the 0.042-ohm resistor causes a voltage drop, low voltage is applied to the starter motor and damage from an otherwise high torque is prevented. The time-delay relay returns to its normal "closed" position since no difference in potential exists between the time-delay relay coil terminals with the acceleration relay contacts closed.

The closed time-delay relay completes a circuit to the motor relay coil (figure 5–12). With the motor relay energized, a complete circuit exists through the relay and the series relay coil to the starter, bypassing the 0.042-ohm resistor.

When current of 200 amperes or more flows to the starter, the series relay coil is energized sufficiently to close the series relay contacts. The starter switch may then be allowed to return to its normal "off" position because the starter circuit is complete through the stop relay and the series relay contacts to the motor relay coil.

As the starter motor increases in r.p.m., a counter-electromotive force builds up enough to allow the series relay to open and break the circuit to the motor relay. Therefore, the starting period is controlled automatically by the speed of the starter motor.

Starter-Generator Starting System

Many gas turbine aircraft are equipped with starter-generator systems. These starting systems use a combination starter-generator which operates as a starter motor to drive the engine during starting; and, after the engine has reached a self-sustain-

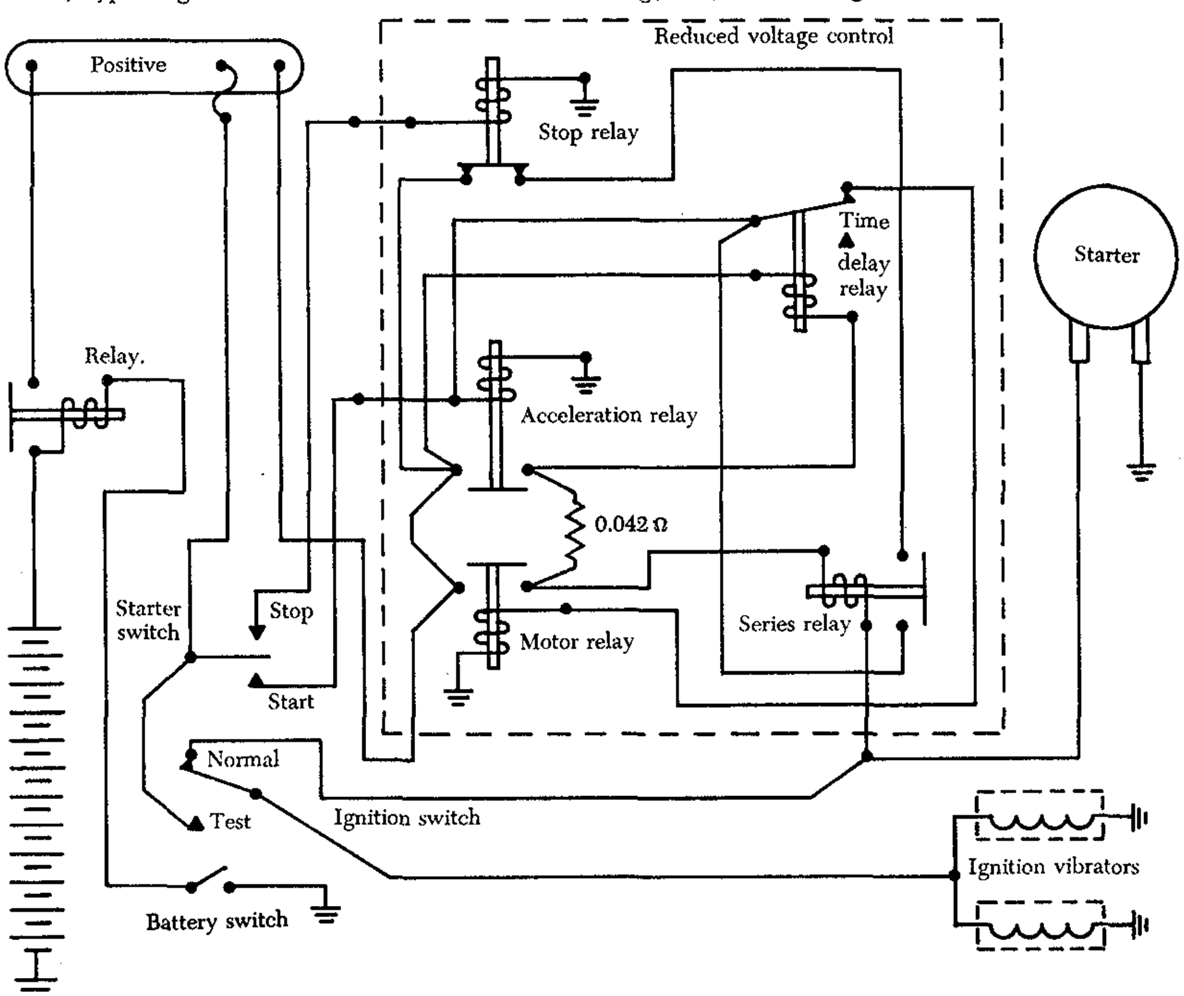

FIGURE 5–12. Reduced voltage control circuit for gas turbine, direct-cranking starting system.

ing speed, operates as a generator to supply the electrical system power.

The starter-generator unit, shown pictorially and schematically in figure 5–13, is basically a shunt generator with an additional heavy series winding. This series winding is electrically connected to produce a strong field and a resulting high torque for starting.

Starter-generator units are desirable from an economical standpoint, since one unit performs the functions of both starter and generator. Additionally, the total weight of starting system components is reduced, and fewer spare parts are required.

The starter-generator internal circuit shown in figure 5–14 has four field windings: (1) A series field ("C" field), (2) a shunt field, (3) a compensating field, and (4) an interpole or commutating winding. During starting, the series ("C" field), compensating, and commutating windings are used. The unit is similar to a direct-cranking starter since all of the windings used during starting are in series with the source. While acting as a starter, the unit makes no practical use of its shunt field. A source of 24 volts and 1,500 amperes is usually required for starting.

When operating as a generator, the shunt, compensating, and commutating windings are used. The "C" field is used only for starting purposes. The shunt field is connected in the conventional voltage control circuit for the generator. Compensating and commutating (interpoles) windings provide almost sparkless commutation from no load to full load.

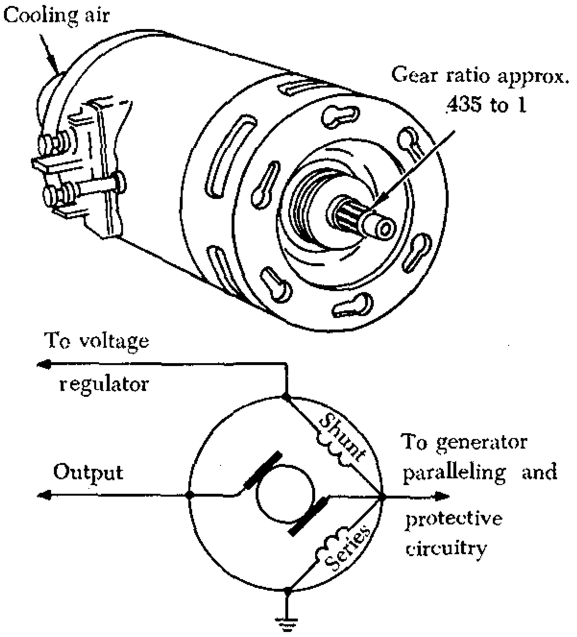

FIGURE 5–13. Typical starter-generator.

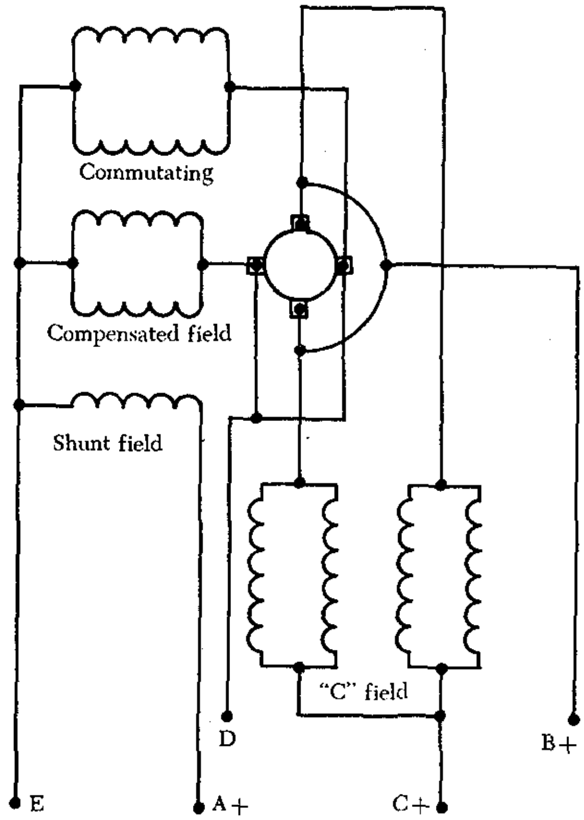

FIGURE 5–14. Starter-generator internal circuit.

Figure 5–15 illustrates the external circuit of a starter-generator with an undercurrent controller. This unit controls the starter-generator when it is used as a starter. Its purpose is to assure positive action of the starter and to keep it operating until the engine is rotating fast enough to sustain combustion. The control block of the undercurrent controller contains two relays; one is the motor relay, which controls the input to the starter. The other, the undercurrent relay, controls the operation of the motor relay.

The sequence of operation for the starting system shown in figure 5–15 is discussed in the following paragraphs.

To start an engine equipped with an undercurrent relay, it is first necessary to close the engine master switch. This completes the circuit from the aircraft's bus to the start switch, to the fuel valves, and to the throttle relay. Energizing the throttle relay starts the fuel pumps, and completing the fuel valve circuit gives the necessary fuel pressure for starting the engine.

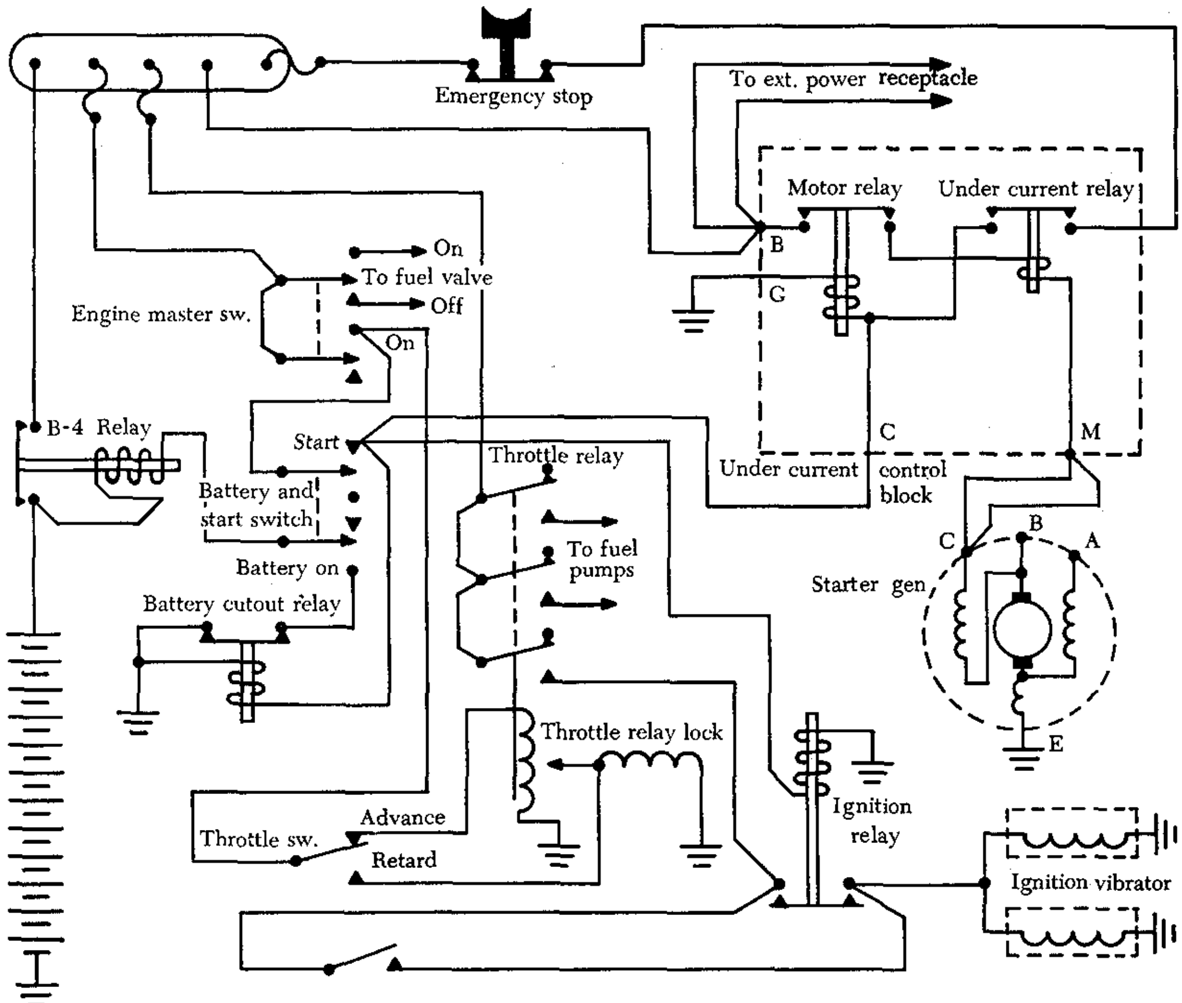

FIGURE 5–15. Starter-generator circuit.

As the battery and start switch is turned on, three relays close. They are the motor relay, the ignition relay, and the battery cutout relay. The motor relay closes the circuit from the power source to the starter motor; the ignition relay closes the circuit to the ignition units; and the battery cutout relay disconnects the battery. (Opening the battery circuit is necessary because the heavy drain of the starter motor would damage the battery.)

Closing the motor relay allows a very high current to flow to the motor. Since this current flows through the coil of the undercurrent relay, it closes. Closing the undercurrent relay completes a circuit from the positive bus to the motor relay coil, ignition relay coil, and battery cutout relay coil. The start switch is allowed to return to its normal "off" position, and all units continue to operate.

As the motor builds up speed, the current draw of the motor begins to decrease, and as it decreases to less than 200 amps, the undercurrent relay opens. This action breaks the circuit from the positive bus to the coils of the motor, ignition, and battery cutout relays. The de-energizing of these relay coils halts the start operation.

After the procedures described are completed, the engine should be operating efficiently and ignition should be self-sustaining. If, however, the engine fails to reach sufficient speed to halt the starter operation, the stop switch may be used to break the circuit from the positive bus to the main contacts of the undercurrent relay.

On a typical aircraft installation, one starter-generator is mounted on each engine gearbox. During starting, the starter-generator unit functions as a d.c. starter motor until the engine has reached a predetermined self-sustaining speed. Aircraft equipped with two 24-volt batteries can supply the electrical load required for starting by operating the batteries in a series configuration.

The following description of the starting procedure used on a four-engine turbojet aircraft equipped with starter-generator units is typical of most starter-generator starting systems.

Starting power, which can be applied to only one starter-generator at a time, is connected to a terminal of the selected starter-generator through a corresponding starter relay. Engine starting is controlled from an engine start panel. A typical start panel (figure 5–16) contains the following switches: an engine selector switch, a power selector switch, an air start switch, and a start switch.

The engine selector switch shown in figure 5–16 has five positions ("1," "2," "3," "4," and "OFF") and is turned to the position corresponding to the engine to be started. The power selector switch is used to select the electrical circuit applicable to the power source (ground power unit or battery) being used. The air-start switch, when placed in the "NORMAL" position, arms the ground starting circuit. When placed in the "AIR START" position, the igniters can be energized independently of the throttle ignition switch. The start switch when in the "START" position completes the circuit to the starter-generator of the engine selected to be started, and causes the engine to rotate. The engine start panel shown also includes a battery switch.

When an engine is selected with the engine selector switch, and the start switch is held in the "START" position, the starter relay corresponding to the selected engine is energized and connects that engine's starter-generator to the starter bus. When the start switch is placed in the "START" position, a start lock-in relay is also energized. Once energized, the start lock-in relay provides its own holding circuit and remains energized providing closed circuits for various start functions.

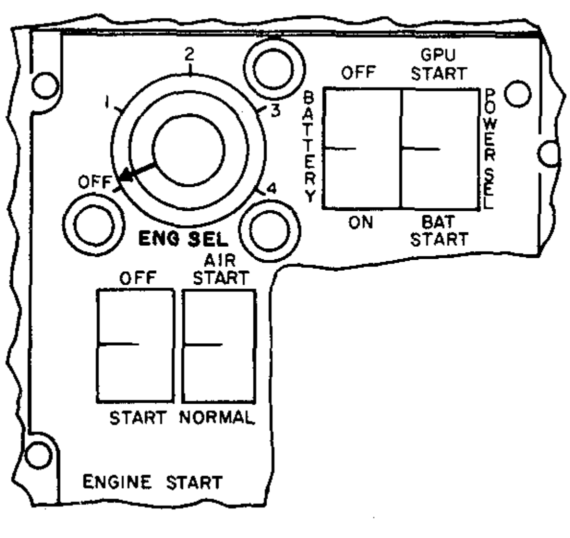

FIGURE 5–16. Engine start panel.

An overvoltage lockout relay is provided for each starter-generator. During ground starting, the overvoltage lockout relay for the selected starter-generator is energized through the starting control circuits. When an overvoltage lockout relay is energized, overvoltage protection for the selected starter-generator is suspended. A bypass of the voltage regulator for the selected starter-generator is also provided to remove undesirable control and resistance from the starting shunt field.

On some aircraft a battery lockout switch is installed in the external power receptacle compartment. When the door is closed, activating the switch, the ground starting control circuits function for battery starting only. When the door is open, only external power ground starts can be accomplished.

A battery series relay is also a necessary unit in this starting system. When energized, the battery series relay connects the two 24-volt batteries in series to the starter bus, providing an initial starting voltage of 48 volts. The large voltage drop which occurs in delivering the current needed for starting reduces the voltage to approximately 20 volts at the instant of starting. The voltage gradually increases as starter current decreases with engine acceleration and the voltage on the starter bus eventually approaches its original maximum of 48 volts.

Some multi-engine aircraft equipped with starter-generators include a parallel start relay in their starting system. After the first two engines of a four-engine aircraft are started, current flow for starting each of the last two engines passes through a parallel start relay which shifts the battery output from series to parallel. When starting the first two engines, the starting power requirement necessitates connecting the two batteries in series. After two or more engine generators are providing power, the combined power of the batteries in series is not required. Thus, the battery circuit is shifted from series to parallel when the parallel start relay is energized.

To start an engine with the aircraft batteries, the start switch is placed in the "START" position (figure 5–16). This completes a circuit through a circuit breaker, the throttle ignition switch, and the engine selector switch to energize the start lock-in relay. Power then has a path from the start switch through the "BAT START" position of the power selector switch to energize the battery series relay, which connects the aircraft batteries in series to the starter bus.

Energizing the No. 1 engine's starter relay directs power from the starter bus to the No. 1 starter-generator, which then cranks the engine.

At the time the batteries are connected to the starter bus, power is also routed to the appropriate bus for the throttle ignition switch. The ignition system is connected to the starter bus through an overvoltage relay which does not become energized until the engine begins accelerating and the starter bus voltage reaches about 30 volts.

As the engine is turned by the starter to approximately 10% r.p.m., the throttle is advanced to the "IDLE" position. This action actuates the throttle ignition switch, energizing the igniter relay. When the igniter relay is closed, power is provided to excite the igniters and fire the engine.

When the engine reaches about 25 to 30% r.p.m., the start switch is released to the "OFF" position. This removes the start and ignition circuits from the engine start cycle, and the engine accelerates under its own power.

Troubleshooting a Starter-Generator Starting System

The procedures listed in table 7 are typical of those used to repair malfunctions in a starter-generator starting system similar to the system described in this section. These procedures are presented as a guide only. The appropriate manufacturer's instructions and approved maintenance directives should always be consulted for the aircraft involved.

AIR TURBINE STARTERS

The air turbine starters are designed to provide high starting torque from a small, lightweight source. The typical air turbine starter weighs from one-fourth to one-half as much as an electric starter capable of starting the same engine. It is capable of developing twice as much torque as the electric starter.

The typical air turbine starter consists of an axial flow turbine which turns a drive coupling through

TABLE 7. Starter-Generator Starting System Troubleshooting Procedures.

PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
Engine Does Not Rotate During Start Attempt:		
Low supply voltage to the starter.	Check voltage of the battery or external power source.	Adjust voltage of the external power source or charge batteries.
Power switch is defective.	Check switch for continuity.	Replace switch.
Ignition switch in throttle quadrant.	Check switch for continuity.	Replace switch.
Start-lockout relay energized.	Check position of generator control switch.	Place switch in "OFF" position.
Battery series relay is defective.	With start circuit energized, check for 48 volts d.c. across battery series relay coil.	Replace relay if no voltage is present.
Starter relay is defective.	With start circuit energized, check for 48 volts d.c. across starter relay coil.	Replace relay if no voltage is present.
Defective starter.	With start circuit energized, check for proper voltage at the starter.	If voltage is present, replace the starter.
Start lock-in relay defective.	With start circuit energized, check for 28 volts d.c. across the relay coil.	Replace relay if voltage is not present.
Starter drive shaft in component drive gearbox is sheared.	Listen for sounds of starter rotation during an attempted start. If the starter rotates but the engine does not, the drive shaft is sheared.	Replace the engine.
Engine Starts But Does Not Accelerate To Idle:		
Insufficient starter voltage.	Check starter terminal voltage.	Use larger capacity ground power unit or charge batteries.
Engine Fails To Start When Throttle Is Placed In Idle:		
Defective ignition system.	Turn on system and listen for spark-igniter operation.	Clean or replace spark igniters, or replace exciters, or leads to igniters.

a reduction gear train and a starter clutch mechanism.

The air to operate an air turbine starter is supplied from either a ground-operated compressor or the bleed air from another engine. Auxiliary compressed-air bottles are available on some aircraft for operating the air turbine starter.

Figure 5–17 is a cutaway view of an air turbine starter. The starter is operated by introducing air of sufficient volume and pressure into the starter inlet. The air passes into the starter turbine housing, where it is directed against the rotor blades by the nozzle vanes, causing the turbine rotor to turn. As the rotor turns, it drives the reduction gear train and clutch arrangement, which includes the rotor pinion, planet gears and carrier, sprag clutch assembly, output shaft assembly, and drive coupling.

The sprag clutch assembly engages automatically as soon as the rotor starts to turn, but disengages as soon as the drive coupling turns more rapidly than the rotor side. When the starter reaches this overrun speed, the action of the sprag clutch allows the gear train to coast to a halt. The output shaft assembly and drive coupling continue to turn as long as the engine is running.

A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when the starter reaches cutout speed. Opening the turbine switch interrupts an electrical signal to the pressure-regulating valve. This closes the valve and shuts off the air supply to the starter.

The turbine housing contains the turbine rotor, the rotor switch actuator, and the nozzle components

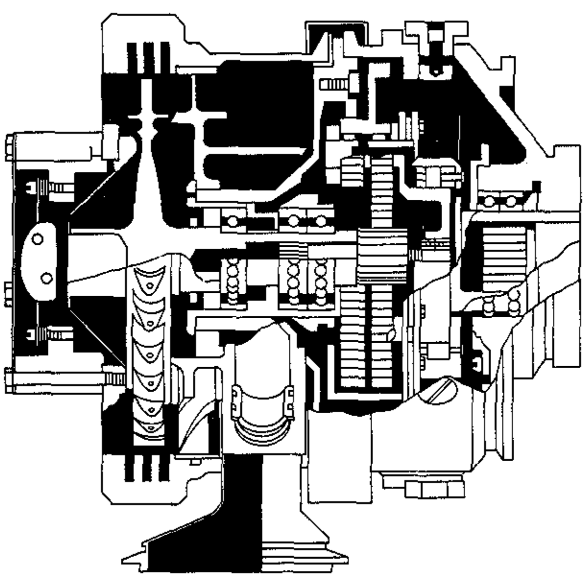

FIGURE 5–17. Cutaway of an air turbine starter.

which direct the inlet air against the rotor blades. The turbine housing incorporates a turbine rotor containment ring designed to dissipate the energy of blade fragments and direct their discharge at low energy through the exhaust duct in the event of rotor failure due to excessive turbine overspeed.

The transmission housing contains the reduction gears, the clutch components, and the drive coupling. The transmission housing also provides a reservoir for the lubricating oil. Oil is added to the transmission housing sump through a port at the top of the starter. This port is closed by a vent plug containing a ball valve which allows the sump to be vented to the atmosphere during normal flight, but prevents loss of oil during inverted flight. The housing also incorporates two oil-level holes, which are used to check the oil quantity. A magnetic drain plug in the transmission drain opening attracts any ferrous particles which may be in the oil.

The ring gear housing, which is internal, contains the rotor assembly. The switch housing contains the turbine switch and bracket assembly.

To facilitate starter installation and removal, a mounting adapter is bolted to the mounting pad on the engine. Quick-detach clamps join the starter to the mounting adapter and inlet duct. Thus, the starter is easily removed for maintenance or overhaul by disconnecting the electrical line, loosening the clamps, and carefully disengaging the drive coupling from the engine starter drive as the starter is withdrawn.

The air turbine starter shown in figure 5–17 is used to start large gas turbine engines. The starter is mounted on an engine pad, and its drive shaft is splined by mechanical linkage to the engine compressor. Air from any suitable source, such as a ground-operated or airborne compressor unit, is used to operate the starter. The air is directed through a combination pressure-regulating and shutoff valve in the starter inlet ducting. This valve regulates the pressure of the starter operating air and shuts off the air supply when the maximum allowable starter speed has been reached.

The pressure-regulating and shutoff valve, shown in figure 5–18, consists of two subassemblies: (1) The pressure-regulating valve and (2) the pressure-regulating valve control.

The regulating valve assembly consists of a valve housing containing a butterfly-type valve (figure 5–18). The shaft of the butterfly valve is connected through a cam arrangement to a servo piston. When the piston is actuated, its motion on the cam causes

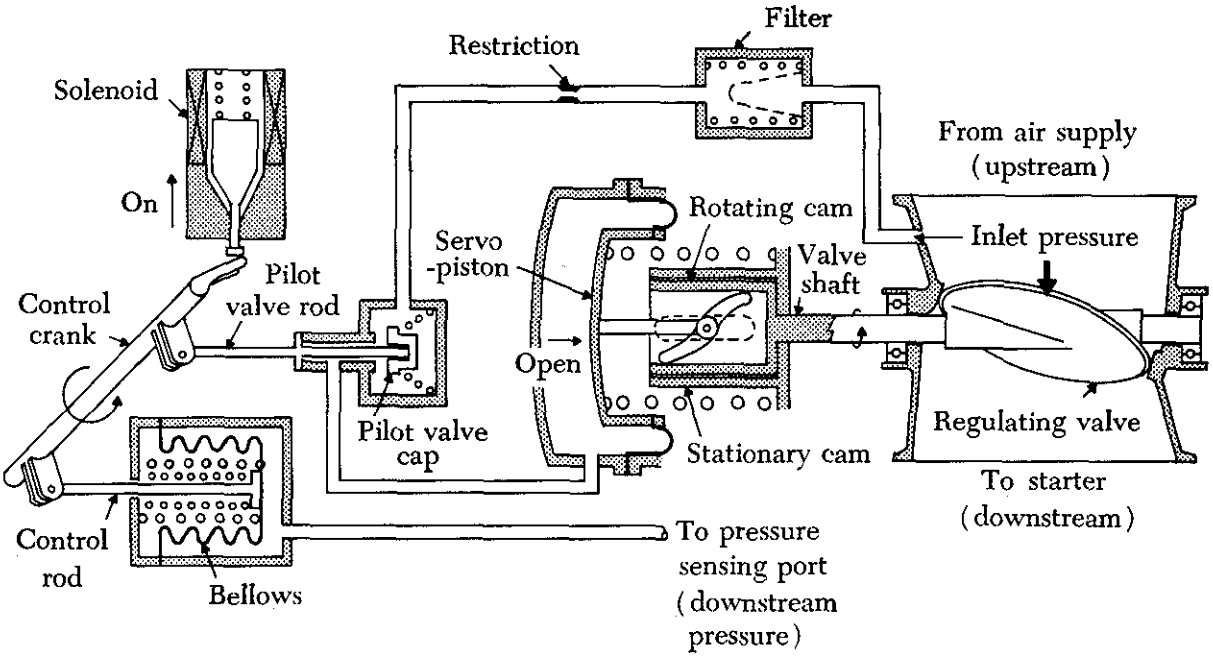

FIGURE 5–18. Pressure-regulating and shutoff valve in "on" position.

rotation of the butterfly valve. The slope of the cam track is designed to provide small initial travel and high initial torque when the starter is actuated. The cam track slope also provides more stable action by increasing the opening time of the valve.

The control assembly is mounted on the regulating valve housing and consists of a control housing in which a solenoid is used to stop the action of the control crank in the "off" position (figure 5–18). The control crank links a pilot valve, which meters pressure to the servo piston, with the bellows connected by an air line to the pressure-sensing port on the starter.

Turning on the starter switch energizes the regulating valve solenoid. The solenoid retracts and allows the control crank to rotate to the "open" position. The control crank is rotated by the control rod spring moving the control rod against the closed end of the bellows. Since the regulating valve is closed and downstream pressure is negligible, the bellows can be fully extended by the bellows spring.

As the control crank rotates to the open position, it causes the pilot valve rod to open the pilot valve allowing upstream air, which is supplied to the pilot valve through a suitable filter and a restriction in the housing, to flow into the servo piston chamber. The drain side of the pilot valve, which bleeds the servo chamber to the atmosphere, is now closed by the pilot valve rod and the servo piston moves inboard (figure 5–18). This linear motion of the servo piston is translated to rotary motion of the valve shaft by the rotating cam, thus opening the regulating valve. As the valve opens, downstream pressure increases. This pressure is bled back to the bellows through the pressure-sensing line and compresses the bellows. This action moves the control rod, thereby turning the control crank and moving the pilot valve rod gradually away from the servo chamber to vent to the atmosphere (figure 5–18). When downstream (regulated) pressure reaches a preset value, the amount of air flowing into the servo through the restriction equals the amount of air being bled to the atmosphere through the servo bleed and the system is in a state of equilibrium.

When the valve is open, the regulated air passing through the inlet housing of the starter impinges on the turbine, causing it to turn. As the turbine turns, the gear train is activated and the inboard clutch gear, which is threaded onto a helical screw, moves forward as it rotates and its jaw teeth engage those of the outboard clutch gear to drive the output shaft of the starter. The clutch is an overrunning type to facilitate positive engagement and minimize chatter. When starting speed is reached, a set of flyweights in a centrifugal cutout switch actuates a plunger which breaks the ground circuit of the solenoid.

When the ground circuit is broken, and the solenoid is de-energized, the pilot valve is forced back to the "off" position, opening the servo chamber to the atmosphere (see figure 5–19). This action allows the actuator spring to move the regulating valve to the "closed" position. To keep leakage to a minimum in the "off" position, the pilot valve incorporates an inner cap which seals off the upstream pressure to the servo and the servo chamber bleed passage.

When the air to the starter is terminated, the outboard clutch gear, driven by the engine, will begin to turn faster than the inboard clutch gear, and the inboard clutch gear, actuated by the return spring, will disengage the outboard clutch gear, allowing the rotor to coast to a halt. The outboard clutch shaft will continue to turn with the engine.

Air Turbine Starter Troubleshooting Guide

The troubleshooting procedures listed in table 8 are applicable to air turbine starting systems equipped with a combination pressure-regulating and shutoff valve. These procedures should be used as a guide only, and are not intended to supplant the manufacturer's instructions.

Turbine Engine Cartridge Starters

The turbine engine cartridge starter, sometimes called the solid-propellant starter, is used on some large turbine engines. It is similar in operation to the air turbine starter, but must be constructed to withstand the high temperatures resulting from burning a solid-propellant charge to supply the energy for starting. Protection is also provided against excessive torque pressures and overspeeding of the starter turbine.

Since cartridge starters are similar in operation to air turbine starters, some manufacturers make available a turbine engine starter that can be operated using gas generated by a cartridge, compressed air from a ground supply cart, or engine cross-bleed air. A typical cartridge/pneumatic starter is described in detail in the next section.

CARTRIDGE / PNEUMATIC TURBINE ENGINE STARTER

A typical cartridge/pneumatic turbine engine starter is shown in figure 5–20. This type of starter may be operated as an ordinary air turbine starter, from a ground-operated air supply or an engine cross-bleed source. It may also be operated as a cartridge starter.

The principal components of the cartridge starter are illustrated in the schematic diagram of figure 5–21. Reference to this diagram will facilitate understanding of the following discussion of a typical cartridge starter operation.

To accomplish a cartridge start, a cartridge is first placed in the breech cap. The breech is then closed on the breech chamber by means of the breech handle and rotated a part-turn to engage the lugs between the two breech sections. This rotation

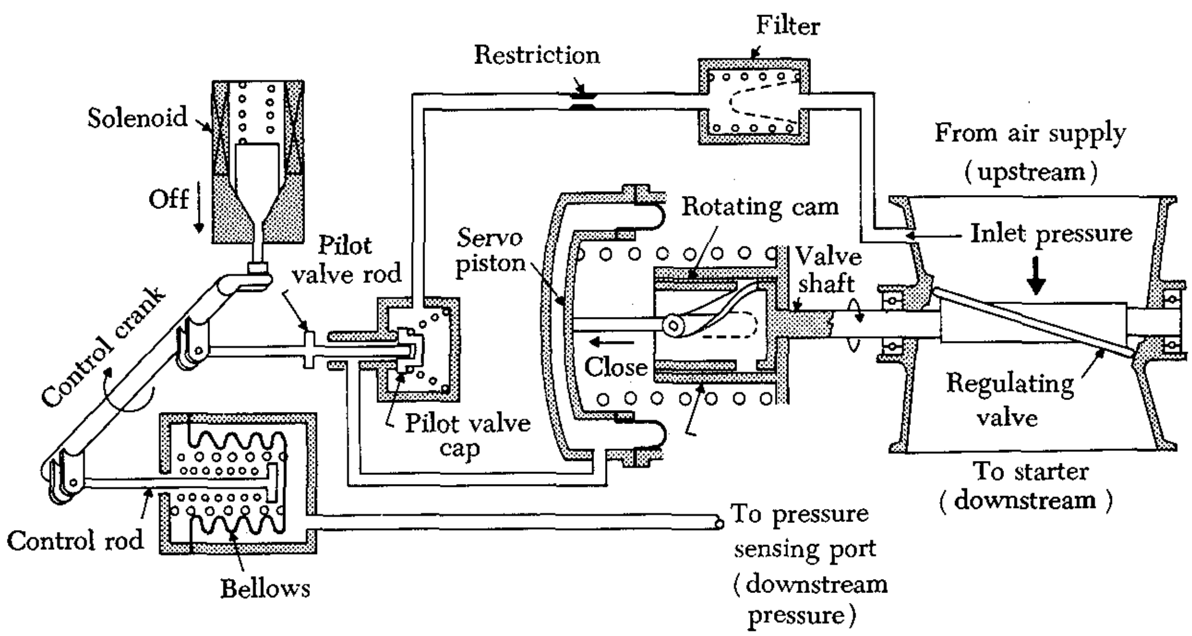

FIGURE 5–19. Pressure-regulating and shutoff valve in "off" position.

TABLE 8. Air Turbine Starter System Troubleshooting Procedures.

TROUBLE	PROBABLE CAUSE	REMEDY
Starter does not operate (no rotation).	No air supply.	Check air supply.
	Electrical open in cutout switch.	Check switch continuity. If no continuity, remove starter and adjust or replace switch.
	Sheared starter drive coupling.	Remove starter and replace drive coupling.
	Internal starter discrepancy.	Remove and replace starter.
Starter will not accelerate to normal cutoff speed.	Low starter air supply.	Check air source pressure.
	Starter cutout switch set improperly.	Adjust rotor switch actuator.
	Valve pressure regulated too low.	Replace valve.
	Internal starter malfunction.	Remove and replace starter.
Starter will not cut off.	Low air supply.	Check air supply.
	Rotor switch actuator set too high.	Adjust switch actuator assembly.
	Starter cutout switch shorted.	Replace switch and bracket assembly.
External oil leakage.	Oil level too high.	Drain oil and re-service properly.
	Loose vent, oil filler, or magnetic plugs.	Tighten magnetic plug to proper torque. Tighten vent and oil filler plugs as necessary and lockwire.
	Loose clamp band assembly.	Tighten clamp band assembly to higher torque.
Starter runs, but engine does not turn over.	Sheared drive coupling.	Remove starter and replace the drive coupling. If couplings persist in breaking in unusually short periods of time, remove and replace starter.
Starter inlet will not line up with supply ducting.	Improper installation of starter on engine, or improper indexing of turbine housing on starter.	Check installation and/or indexing for conformance with manufacturer's installation instructions and the proper index position of the turbine housing specified for the aircraft.
Metallic particles on magnetic drain plug.	Small fuzzy particles indicate normal wear.	No remedial action required.
	Particles coarser than fuzzy, such as chips, slivers, etc., indicate internal difficulty.	Remove and replace starter.
Broken nozzle vanes.	Large foreign particles in air supply.	Remove and replace starter and check air supply filter.
Oil leakage from vent plug assembly.	Improper starter installation position.	Check installed position for levelness of oil plugs and correct as required in accordance with manufacturer's installation instructions.
Oil leakage at drive coupling.	Leaking rear seal assembly.	Remove and replace starter.

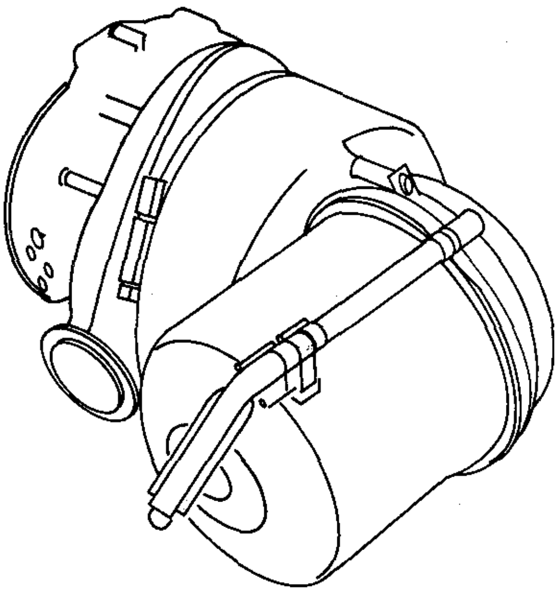

FIGURE 5-20. Cartridge/pneumatic starter.

allows the lower section of the breech handle to drop into a socket and completes the cartridge ignition circuit. Until the ignition circuit is completed, it is impossible to fire the cartridge.

The cartridge is ignited by applying voltage through the connector at the end of the breech handle. This energizes the insulated ignition contact at the entrance of the breech cap, which touches a point on the cartridge itself. The circuit is completed to ground by the ground clip, a part of the cartridge which contacts the inner wall of the breech cap. A schematic of a cartridge/pneumatic starter electrical system is shown in figure 5-22.

Upon ignition, the cartridge begins to generate gas. The gas is forced out of the breech to the hot gas nozzles which are directed toward the buckets on the turbine rotor, and rotation is produced. Gas emerging from the opposite side of the turbine wheel enters an exhaust ring in the exhaust duct, where it is collected and passed out of the starter

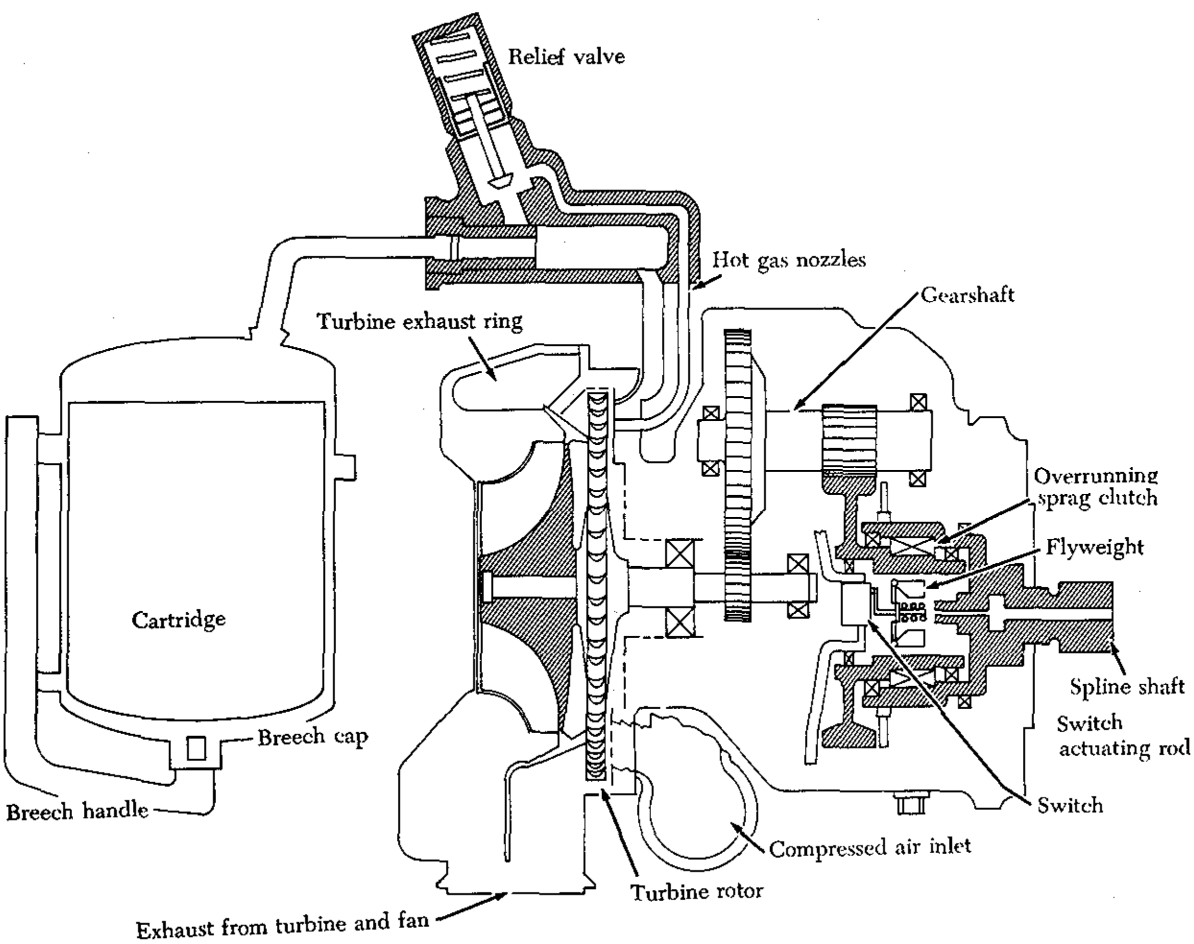

FIGURE 5-21. Cartridge/pneumatic starter schematic.

via the overboard exhaust collector. Before reaching the nozzle, the hot gas passes an outlet leading to the relief valve. This valve directs hot gas to the turbine, bypassing the hot gas nozzle, as the pressure rises above the preset maximum. Thus, the pressure of the gas within the hot gas circuit is maintained at the optimum level.

The cartridge/pneumatic starter can also be operated by compressed air from a ground cart, or by engine cross-bleed air led by ducting on the aircraft to the compressed air inlet. The air passes into the nozzle ring and is directed against the buckets of the turbine rotor by vanes placed around the ring. Rotation is thus produced in essentially the same manner as during a cartridge start. Compressed air leaving the turbine rotor collects in the same exhaust ring and is directed overboard via the exhaust collector.

Whether starting is accomplished by cartridge or compressed air, some opposing force is required to keep turbine speed within safe limits. This opposing force is provided by the aerodynamic braking fan. The fan is connected directly to the turbine shaft. It is supplied with air from the aircraft nacelle and its output is carried off by an exhaust ring concentric with, and located within, the turbine exhaust ring. Hot gas or compressed air exhaust and aerodynamic braking fan output are kept separate up to the overboard exhaust collector.

The gearshaft is part of a two-stage reduction which reduces the maximum turbine speed of approximately 60,000 r.p.m. to an output of approximately 4,000 r.p.m. The large gear of the final output turns the output spline shaft assembly through an overrunning clutch.

The overunning sprag clutch is situated in the output area between the gear shaft on which the final drive gear is located and the output spline shaft assembly. The clutch is a one-way overrunning type; its purpose is to prevent the engine from driving the starter after it begins to operate under its own power. The nature of the sprag clutch is such that it can transmit torque in only one direction. Thus, the driving member can operate through the clutch to deliver its full torque to the engine, but the driven member cannot become the driver, even though revolving in the same direction. Any tendency to do so will disengage the clutch. When the engine has been started and the starter has completed its cycle and stopped, only the output spline shaft assembly and the outer (driven) part of the clutch will be revolving. The other parts of the starter will be at rest.

In the event of a malfunction or lockup of the overrunning output clutch, the engine would, without other safety provision, drive the starter up to a speed above the design "burst r.p.m." of the turbine rotor. To prevent this, the starter is designed with a disengaging output spline shaft assembly. This assembly consists of two spring-loaded, splined sections held together by a tension bolt. A series of ratchet teeth interlock the mating sections of the spline. If internal failure causes the engine to exert excessive torque on the shaft, the ratchet teeth will tend to separate the two shaft sections. The separating force is sufficient to shear the

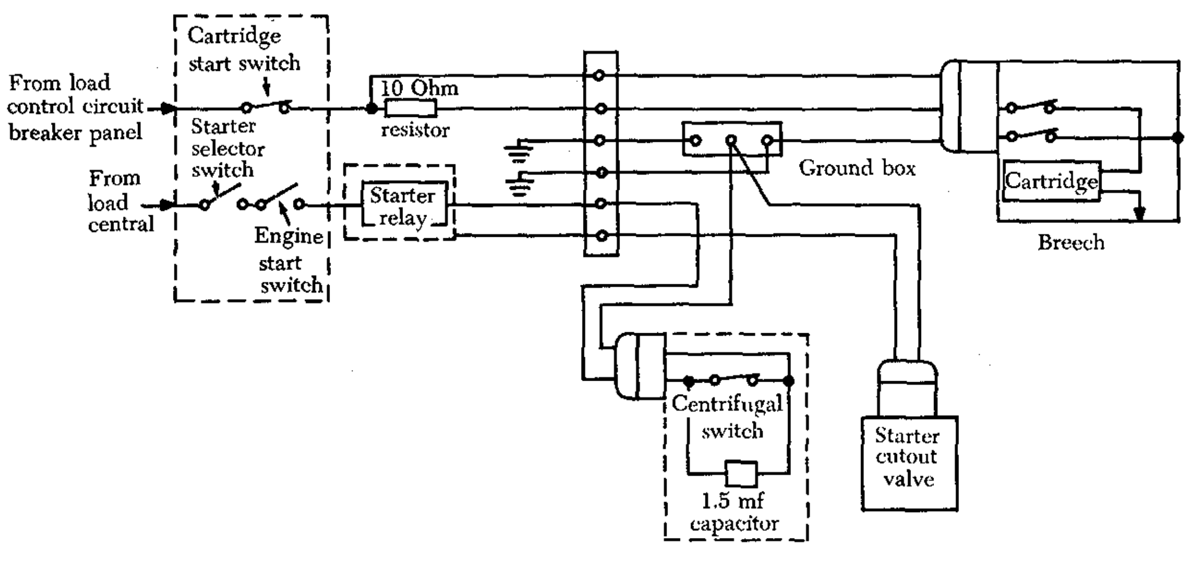

FIGURE 5–22. Cartridge/pneumatic starter electrical schematic.

tension bolt and completely disengage the starter. Both the tension bolt and shaft will shear and disengage the starter if startup torque exceeds the shaft shear section design limits.

During pneumatic starts, a relay shuts off the compressed air when the output has reached a predetermined speed. This is accomplished by an engine-speed sensor which monitors r.p.m. at the starter mounting pad. The sensor is actuated by a pair of flyweights. At speeds below starter cutoff speed, an actuator rod presses against a switch; as the starter approaches cutoff speed, a centrifugal force created by output shaft rotation causes the pair of flyweights to compress a spring, lift the actuator rod, and open the switch. The cutoff speed can be regulated by adjusting the screw that controls the pressure on the spring.

This cartridge/pneumatic starter is lubricated by a splash system. Oil slingers attached to the clutch output race pick up oil from the sump and distribute it throughout the interior of the starter as the output spline revolves. A catching cup construction in the housing, coupled with an oil tube arrangement, carries the oil into the overrunning clutch and other hard-to-reach areas. Since the part to which the slingers are attached is constantly spinning, even after the starter has completed its cycle, starter lubrication continues as long as the aircraft engine is operating. The oil sump contains a magnetic plug to collect contamination.

FUEL/AIR COMBUSTION TURBINE STARTER

The fuel/air combustion starter is used to start both turbojet and turboprop engines by using the combustion energy of conventional jet engine fuel and compressed air. The starter consists of a turbine-driven power unit and auxiliary fuel, air, and ignition systems. Operation of this type starter is, in most installations, fully automatic; actuation of a single switch causes the starter to fire and accelerate the engine from rest to starter cutoff speed.

The combustion starter (figure 5–23) is a gas turbine engine which delivers its power through a high-ratio reduction gear system. The compressed air is normally stored in a shatter-proof cylinder near the combustion gas turbine.

The fuel/air combustion starter was developed primarily for short-flight, air-carrier aircraft. The installed combustion starter provided quick starting at air terminals without ground starting equipment. The use of compressed air cylinders to directly drive a conventional air turbine starter is now replacing fuel/air combustion starters. This type of starting system provides several starts from a bottle of compressed air. Provisions are normally included to re-charge the compressed air cylinder from an installed auxiliary power unit.

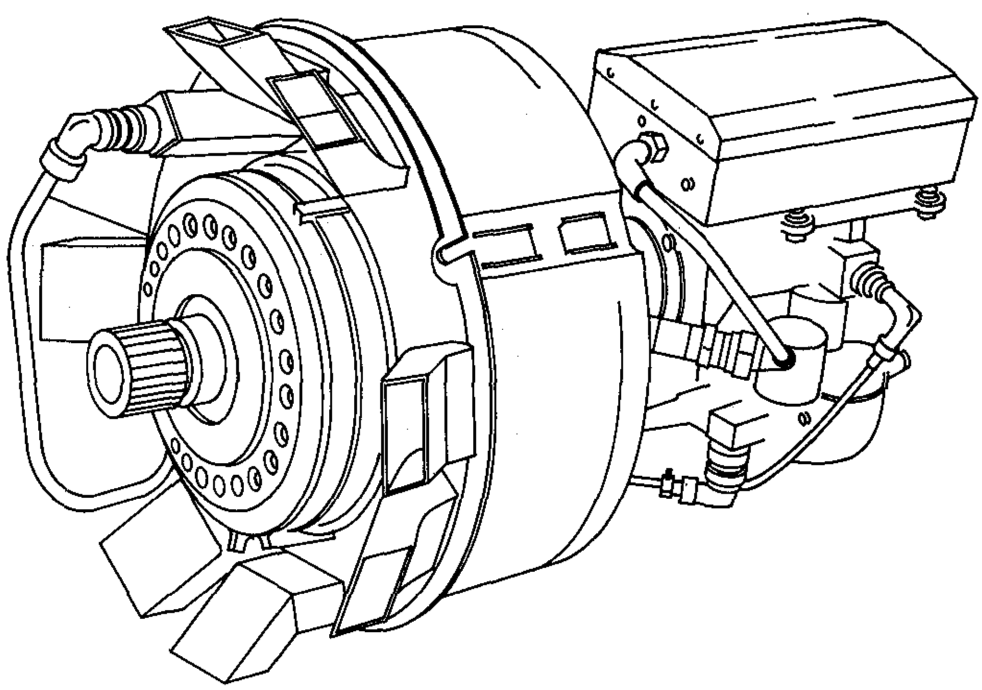

FIGURE 5–23. Fuel/air combustion starter.